ROLE OF TIDAL FORCING IN DETERMINING THE INTERNAL WAVE SPECTRUM IN THE LITTORAL OCEAN

Jeffrey D. Paduan
Department of Oceanography, Code OC/Pd
Naval Postgraduate School
Monterey, CA 93943
phone: (408) 656-3350; fax: (408) 656-2712; email: paduan@nps.navy.mil

Leslie K. Rosenfeld
Department of Oceanography, Code OC/Ro
Naval Postgraduate School
Monterey, CA 93943
phone: (408) 656-3253; fax: (408) 656-2712; email: rosenfel@oc.nps.navy.mil

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LONG-TERM GOALS

The long-range goals of this project are to understand the environmental factors that define the level of internal wave activity in the littoral oceans and to develop re-locatable models capable of predicting these levels. The hypothesis is that energy due to internal tides generated through interactions with complex coastal topography is both predictable, using high-resolution primitive equation numerical models, and responsible for setting energy levels of the broader-frequency internal wave spectrum.

OBJECTIVES

This project seeks support to investigate the nature of internal wave spectra in the littoral ocean environment using existing moored velocity time series and simulated coastal time series produced by a three-dimensional, primitive equation numerical model with realistic bathymetry forced by tidal-period sea level oscillations. This project has very specific goals that relate to the Littoral Internal Wave Initiative (LIWI), which seeks to quantify the physics of oceanic internal waves on the continental slope and shelf and to develop predictive models of their spectral characteristics.

APPROACH

This project builds on the dissertation work of LCDR Emil Petruncio (Naval Postgraduate School, September, 1996). The approach taken is two-pronged: A primitive equation numerical model, the Princeton Ocean Model (POM), is being utilized in a coastal setting where detailed bottom topography and in situ current observations are available. In particular, observations of the spatial variability of the internal tide in and around Monterey Submarine Canyon—from moored observations at depth and High Frequency radar observations at the surface—are being used to validate the ability of the numerical model to reproduce the current patterns. The model is initialized with high resolution side-scan bathymetry and observed stratification over a 100 km x 100 km domain with 1 km resolution and 30 levels. The model is forced with tidally varying sea level at the offshore boundary.

Baroclinic currents generated within the model domain compare well with available observations. In particular, internal tides are generated at the shelf break and along critically sloping bottoms. Large-amplitude waves are observed to propagate along the bottom of the Monterey Submarine Canyon in observations and in idealized model simulations. If details of the phasing and spatial distribution of the internal tide can be confirmed using the high-resolution bathymetry, then the numerical results will be used to compute the integrated baroclinic tidal energy for the entire coastal region. Finally, energy levels of the internal tide under different stratification regimes, as well as for entirely different coastal locations, will be correlated with levels of the broader internal wave spectrum.

WORK COMPLETED

Efforts this year focused on describing observations of the internal tide in Monterey Submarine Canyon along with model simulations using idealized bathymetry. The first publication concentrating on observations (Petruncio et al., 1997) was submitted to the J. Physical Oceanography, revised, and is in final review. A manuscript describing the simulations with idealized shelf, slope, and canyon bathymetry has been written and will also be submitted to the J. Physical Oceanography.

Work was completed on a revised model grid that will allow the tidal boundary conditions—developed by Petruncio in his dissertation and applied, thus far, only to idealized domains—to be used with the realistic bathymetry of Monterey Bay. A grid rotation was required in order to isolate the sea level forcing along the offshore boundary.

A two-week research cruise and month-long mooring deployment within Monterey Submarine Canyon in August 1997 were conducted in support of a joint NSF and ONR/LIWI experiment to measure the level of mixing associated with canyon bathymetry and the internal tide. The data collected is being analyzed for internal tide characteristics, internal wave spectral levels, and turbulent mixing rates. It will form an important part of the validation dataset for this project.

RESULTS

This project has shown the clear influence of bottom topography on the propagation and amplification of internal waves of tidal period. Furthermore, the observations and preliminary model results we have obtained represent direct evidence of the beam-like propagation of these waves in the coastal environment where the waves exist within a few wavelengths of their generation sites.

In situ observations of the internal tide near the bottom of the Monterey Submarine Canyon were obtained during two field Internal Wave Experiments in April (ITEX1) and October (ITEX2) of 1994 (Figure 1). An example of along-canyon current and isopycnal depth time series from two CTD stations separated by about 1/4 wavelength during ITEX1 is shown in Figure 2. Large amplitude isopycnal excursions and velocity fluctuations are seen propagating onshore and upward along the canyon floor. It was hypothesized that the near-critical bottom slope is an important factor in the generation and amplification of this bottom-intensified wave. Model simulations in an idealized canyon with near-critical bottom slope (Figure 3) confirmed the presence of strong, bottom-intensified internal tides (Figure 4).

Other calculations with the idealized model canyon show a bias of tidal-period energy on the southern (right-hand) side of the canyon walls due to the Coriolis effect. Tidal pumping of dense fluid above the rim of the canyon also generates along-coast propagating internal waves. The result is a fairly complicated pattern of variance ellipses at the surface even with the simple, idealized geometry. These results point to the need to incorporate realistic bathymetry in order to interpret HF radar-derived maps of surface tidal currents or subsurface tidal current observations from individual moorings.

IMPACT/APPLICATIONS

The likely impact of this project will be a change in the way predictions of internal wave energy are made for the coastal oceans with a much greater role to be played by limited-area, high-resolution numerical model simulations. If successful, a large part of the current variability for an arbitrary portion of the coastal ocean will be predictable using only a knowledge of local bathymetry and stratification combined with a model of global tide elevations.

TRANSITIONS

Our preliminary results have motivated other research groups to investigate the role of submarine canyons in generating strong internal tides. Our long-range goal is to develop a re-locatable model that can be easily applied to any coastal region for which sufficiently accurate bathymetry and stratification data exists to predict the energy levels of the internal wave field given typical tidal forcing. The obvious transition target for this technology are the modeling groups within the Naval Oceanographic Office responsible for assessing environmental parameters for strategic portions of the coastal oceans.

RELATED PROJECTS

Of direct importance to this project is the NSF-sponsored field program of Leslie Rosenfeld, Mike Gregg, and Eric Kunze designed to observe turbulent mixing in and around Monterey Submarine Canyon driven by the observed internal tide. As described above, the NSF program conducted ship-based and moored observations this past summer that will be incorporated directly into the validation database for this project.

As part of this project, we are collaborating with Prof. Robert Street of Stanford University to collect validation data and help configure his non-hydrostatic model for simulations of the internal tide in Monterey Submarine Canyon. Prof. Street's graduate student, Oliver Fringer, participated in the aforementioned field program. Their work represents a logical extension of our efforts. The non-hydrostatic model is capable of directly simulating more of the high frequency portion of the internal wave band than is the hydrostatic POM. However, it is unlikely that the non-hydrostatic code will be able to extend over realistic bathymetric domains and, therefore, it will not be able to directly simulate the low frequency, tidal end of the internal wave band. We are working toward an initialization of the non-hydrostatic code using output from POM to further investigate the hypothesized cascade of energy from tidal frequencies to the high frequency portion of the internal wave spectrum.

We are collaborating closely with Marlene Noble of the U.S.G.S. who has recently deployed four current meter moorings within our model domain for an entire year. Dr. Noble is also a co-principal investigator with Leslie Rosenfeld and Cynthia Pilskaln on an ONR-sponsored project that collected moored current meter observations from the axis of the Monterey Submarine Canyon out to depths exceeding 2000 m. These data, together with the several long current records from within Monterey Bay, will be used in the model validation and calibration phases of this project.

We are also collaborating closely with several investigators in the use of High Frequency (HF) radars to map surface currents. The two-dimensional descriptions available from this new technology are uniquely capable of tying together the three-dimensional model simulations and point-source mooring observations of tidal fluctuations. We are working with CODAR-type HF radar systems deployed around Monterey Bay. At the same time, we are collaborating with others such as John Vesecky of the University of Michigan, Calvin Teague of Stanford University, Hans Graber of the University of Miami, and Daniel Fernandez of California State University, Monterey Bay who are using and developing other types of HF radar systems. The new multi-frequency HF radar system developed by Profs. Vesecky and Teague is also being operated around Monterey Bay. During October and November, 1997, CODARs, the new multi-frequency radars, and the OSCR system from Miami are all three being operated side-by-side as part of the ONR-sponsored Chesapeake Outflow Plume Experiment (COPE).

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Figure 1 (right). Monterey Bay bathymetry with ITEX1 (*) and ITEX2 (o) CTD stations, S4 mooring station (+), and tide gauge stations (TG) from Petruncio et al. (1997). Dashed line shows an XBT track from ITEX1.

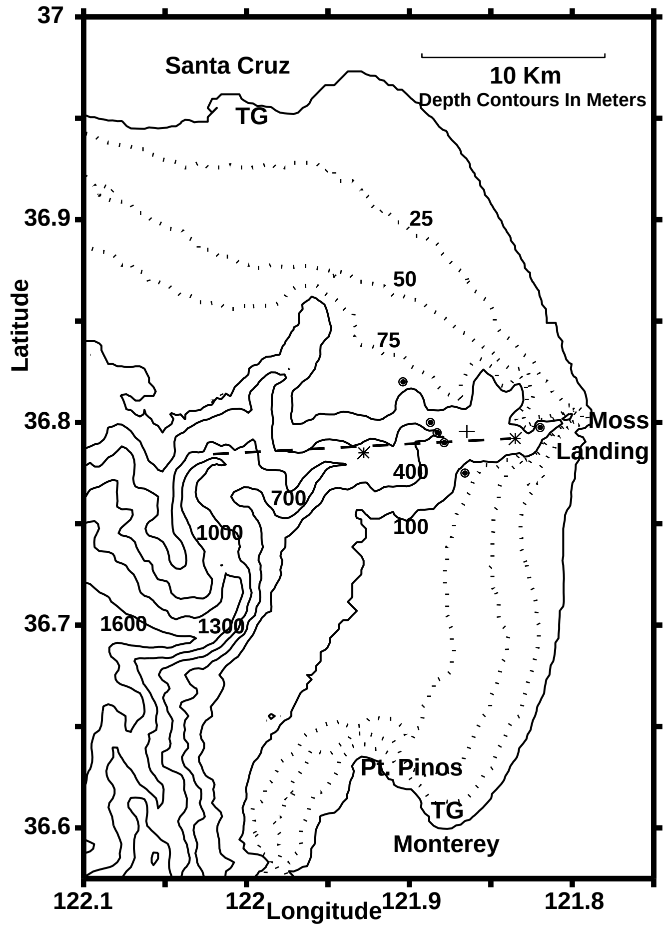

Figure 2 (bottom). Time series of M2-fit east-west velocity component and isopycnal displacements for the deep (left) and shallow (right) CTD stations from ITEX1. Demeaned M2 sea level oscillations exaggerated by a factor of 10 (dashed lines) are also shown.

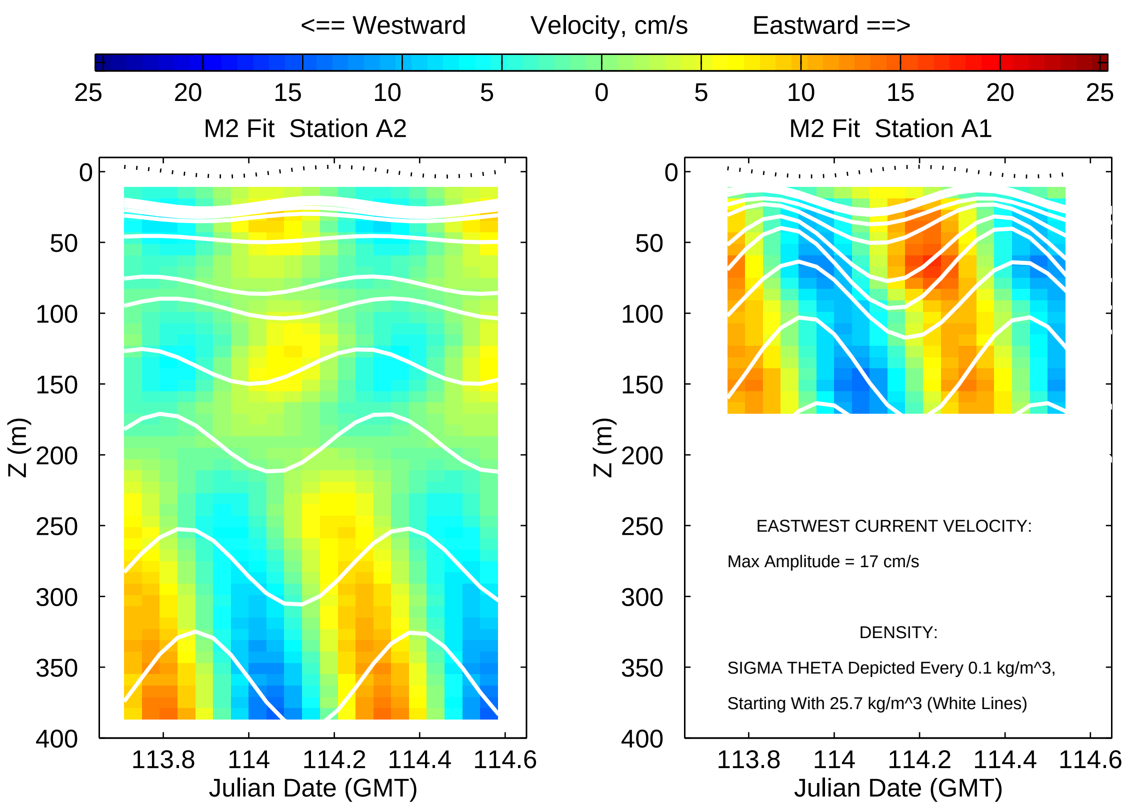

Figure 3. Idealized model bathymetry

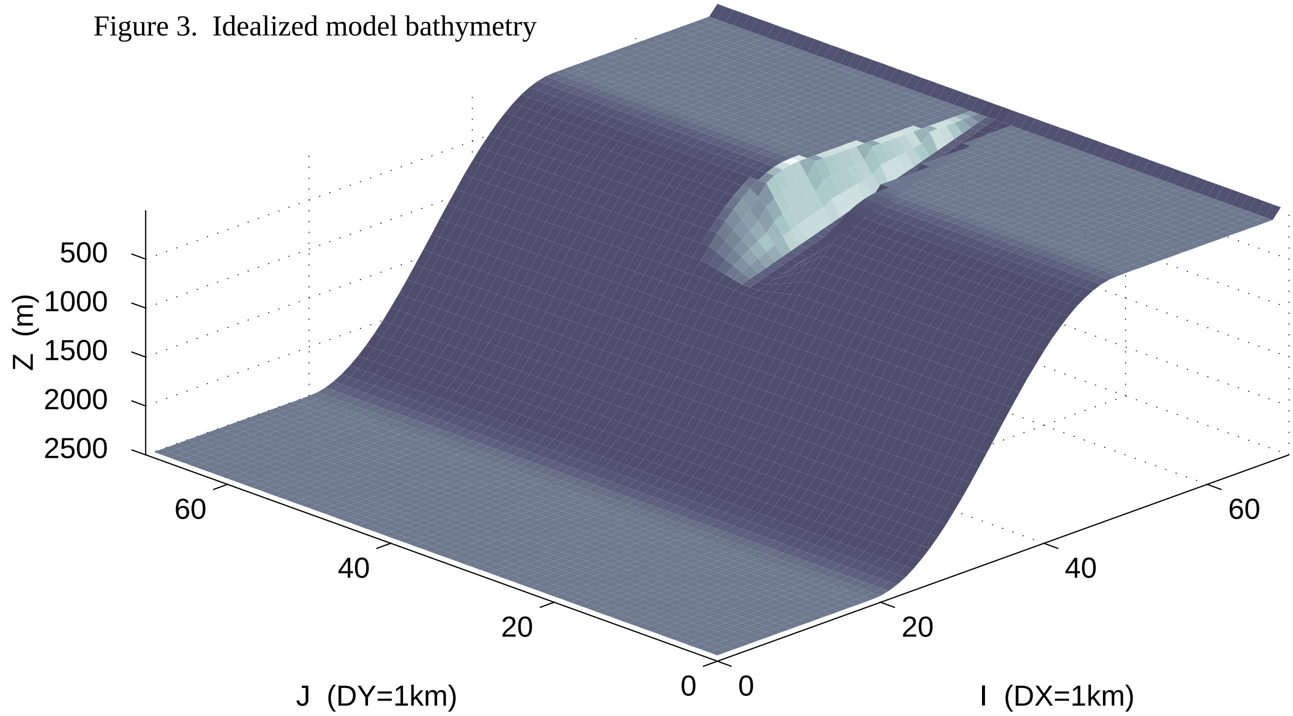

Figure 4. Model velocity snapshots for a section along the canyon axis.